Study of the scientific potential of a three 40 cm Telescopes Interferometer at Dome C.

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ABSTRACT

Recent site testing (see: http://www-luan.unice.fr/Concordiastro/indexantartic.html) has shown that Dome C in Antarctica might have a high potential for stellar interferometry if some solutions related to the surface atmospheric layer are found. A demonstrator interferometer could be envisioned in order to fully qualify the site and prepare the future development of a large array.

We analyse the performances of a prototype interferometer for Dome C made with 3 telescopes of 40 cm diameter. It assumes classical Michelson recombination. The most recent atmospheric and environmental conditions measured at Dome C are considered (see K. Agabi "First whole atmosphere night-time seeing measurements at Dome C, Antarctica"[1]). We also study the possible science reachable with such a demonstrator. Especially we evaluate that even such small aperture interferometer could allow the detection and low resolution spectroscopy of the most favourable pegaside planets.

Keywords: long baseline interferometry, astronomical sites: Antarctica Dome C, extrasolar planets

1. INTRODUCTION

Astronomical observations in infrared are mainly limited by the atmospheric background. This flux depends strongly on the atmospheric temperature and emissivity. That is why the Antarctic should be an interesting place for astronomical observations (Chamberlain, 2000 [2]). Since the forthcoming of permanent stations in Antarctica, more and more research groups are testing atmospheric characteristics there and expect to build science instruments on Antarctic plateau. The size of the projects ranges begin from a small telescope to an ELT or to an optical interferometric array like Kiloparsec Explorer for Optical Planet Search (KEOPS)(Vakili, 2005 [3]). Since a few years the Laboratoire Universitaire Astrophysique de Nice (LUAN) has access to the station Concordia. The site characteristics were investigated. A strong potential of this site for interferometry was pointed out.

2. DOME C, ONE OF THE MOST PROMISING EARTH SITE

2.1. Site description

The Concordia station is located at Dome C, at an altitude of 3300 meters. Since few years the LUAN has been characterizing the atmosphere at Dome C in order to know the real potential of this location. The first results of these tests present Concordia as an exceptional site for astrophysics both for its reduced atmospherics background and for its low atmospheric turbulence during the summer days.

The 210° Kelvin temperature during the winter night implies for this site a very low atmospheric thermal background. The weather is very favorable to astronomical observations with a clear sky 96% of the time (see E. Aristidi, 2005 [4]). These properties show that the Dome C has the clearest atmosphere on earth. This imply the possibility to observe faint objects in infrared more easily than in the other sites. Moreover the background
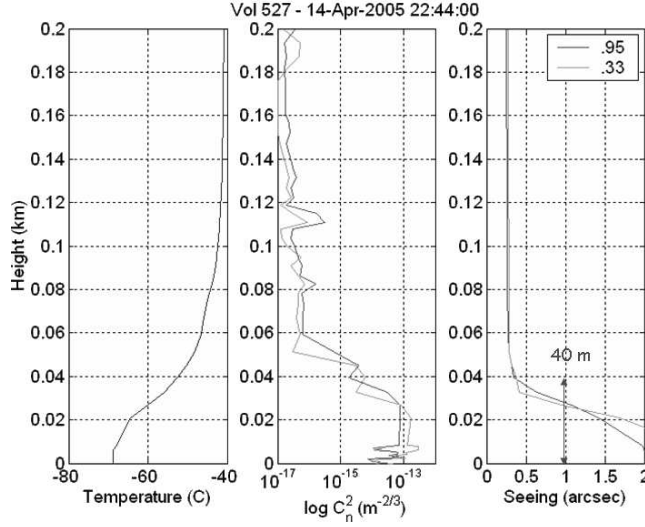
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Figure 1. : C $_n^2$ and temperature and the derived seeing as function as the altitude [4].

fluctuations should have a low amplitude. As the background fluctuation is correlated to the water vapor lines (Miyata, 1999 [5]), the low water concentration at Dome C should imply a low background fluctuation.

The sky brightness is not the only advantage of this site. The seeing of this site is very good too. During summer the mean seeing is 0.2 arcsec and during the winter the value is 1.4 arcsec at the ground level [1]. As shown in the figure 1, the atmospheric turbulence is principally located in the first 30 meter. The 30m high seeing calculated thanks to balloons measurements is of the order of 0.4 arcsec during the winter. In order to reach this low seeing two ways are studied: a ground adaptive optic system or elevating the telescopes over the turbulence layer.

All these results present the Dome C as an exceptional site for "classical" telescopes but it has also interesting characteristics for interferometers. The coherence time is 6.8 ms; It is twice as large as the one on the best actual interferometer site (Paranal). Moreover the atmosphere at Dome C has a low outer scale (and a high inner scale) which implies that the piston should be small. The last important parameter of an interferometer site is the isopistonic angle θ_0. θ_0 at Dome C is 6.8 arc sec, which is 3 times larger than the one at Paranal or 2 times upper than the one at Maidanak. Such isopistonic angle will help to find a reference object needed for faint observations. In the following proceeding, the only thermal noise and the readout noise were considered in our evaluations.

3. BACKGROUND SIMULATIONS AND EXPECTED SCIENCE WITH A THREE 40 CM INTERFEROMETER

3.1. Thermal background simulated for Dome C

In order to evaluate the real potential of an instrument at Dome C, we simulated the fundamental noises. First, the sky and instrument thermal backgrounds are presented. The flux from the thermal emission is simulated thanks to a black body emission. The simulated telescopes are assumed to be perfect, vibrations and the residual error from fringe tracking are neglected. The field of view of the system is given by the following equation:

$$NA = (1.22\lambda/D)^2\pi^2(D)^2, \tag{1}$$

Where NA is the field of view λ the working wavelength and D is the telescope diameter.
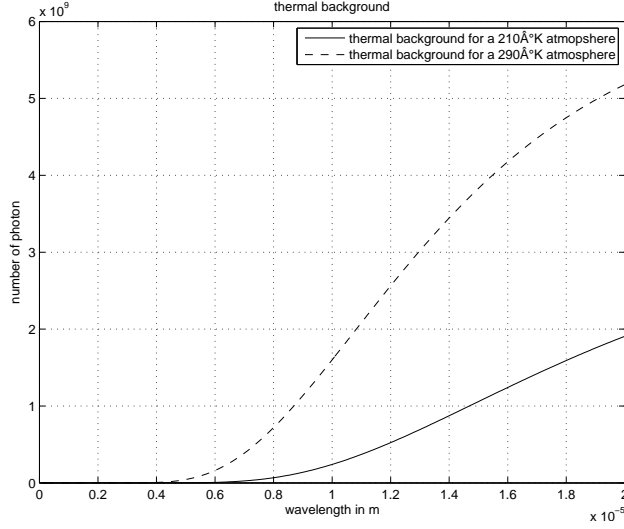
Figure 2. : Thermal background calculated for Dome C (210^oK) and Paranal (290^oK) conditions.

The thermal emission of the atmosphere and the telescope is compared on figure 2 with the background of a same system at 290^oK (typically the temperature of the atmosphere at Paranal). These simulations show that the atmospheric background level at Dome C is 3 times fainter than the one measured at Paranal.

In order to be able to compare the background flux to a science source and hot Jupiter signal, a flux calculation was carried out and exposed in the next subsection.

3.2. Flux from a star and a hot Jupiter received by a 40cm telescopes interferometers, differential phase closure measurement

A black body emitting at the stellar temperature simulates the star emission. The planet emission is simulated by the sum of a black body emitting at the planet temperature and the reflection of the star flux on the planet surface.

The modelling of the planet emission with a black body is a rough approximation. This approximation is pessimistic in Near infrared (J,H,K) but in far infrared the simulations should be carried out with other atmospheric model [Barman, 2000 [6]]. The albedo of the hot Jupiter is around 0.1. The position of the planet was taken as the most favorable, and we consider that one half of the planet receives and reflects the light from the star. For this article three hot Jupiter's were selected and simulated. Their characteristics are exposed in the following tables.

Table 1. Property of the host stars for the hot Jupiter systems of interest

star	system distance (parsec)	spectral type	K mag	V mag	star diameter (km)	star temperature (^{o}K)
HD108147	38.5	F8	5.72	6.98	970850.1	6130
HD13445 (GJ86)	10.9	K1	4.13	6.12	650274.9	5350
HD179949	27	F8	4.94	6.24	983249.7	6100

The stars radii are calculated thanks to the following empiric formula (Kervella, 2004 [7]):

$$\log \theta_{LD} = c_\lambda (C_0 - C_1) + d_\lambda - 0.2C_0, \tag{2}$$

comparison between flux of the star and flux from the planete observed on Earth
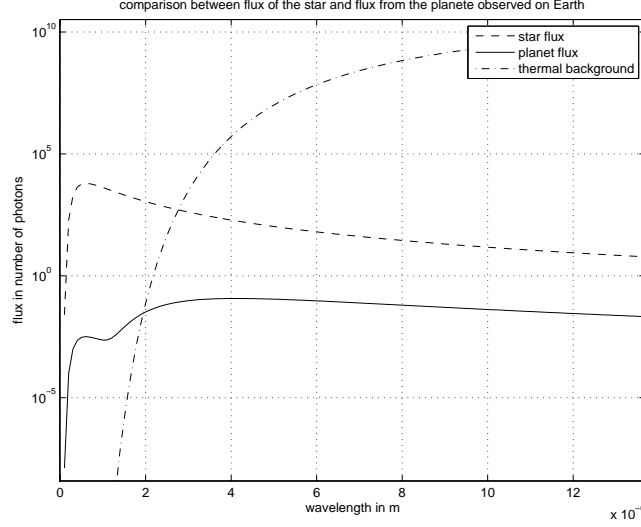
Figure 3. : The planet, star and thermal background flux received by a 40cm telescope based on earth. The simulated system is HD108147 with a exposure time of 10ms, the transmission is 10%

Where θ_{LD} is the angular diameter of the star in mas, C_0 and C_1 are any two distinct colors of the Johnson system, and c_λ and d_λ are two factor depending on the spectral band of C_0 and C_1.

Table 2. Characteristics of the interesting hot Jupiter

star	separation (AU)	planet temperature (^oK)	planet mass(M_{Jup})	planet diameter (km)
HD108147	0.104	890	0.4	200177
HD13445 (GJ86)	0.11	800	4.01	157282
HD179949	0.04	1160	0.98	150133,2

The planet diameter is calculated thanks to the empiric formula given by Guillot (Guillot, 1999 [8]). The flux resulting from the simulation for the less favorable case (HD108147) are plotted on the figure 3.

The planet detection can be carried out thanks to the differential method (Vannier, 2006 [9]). In order to know the best spectral band to detect hot Jupiter the signal to noise ratio should be calculated. The fundamental limitation in the hot Jupiter detection is the thermal background emission and the readout noise.

3.3. Signal to noise ratio for hot Jupiter detection

In the previous subsection we saw that the highest part of the planetary signal is overflowed by the thermal background. The thermal noise should be calculated in order to define the best working wavelength and the observation time needed to reach a good signal to noise ratio (Vannier, 2006 [9]). The phase error from fundamental noise is (3)[9].

$$\sigma = \sqrt{3}\frac{\sqrt{((\sigma_{phot}^2 + Mnp\sigma_{read}^2 + \sigma_{th}^2)/2)}}{(CN(\lambda_i)/n_{tel})} \tag{3}$$
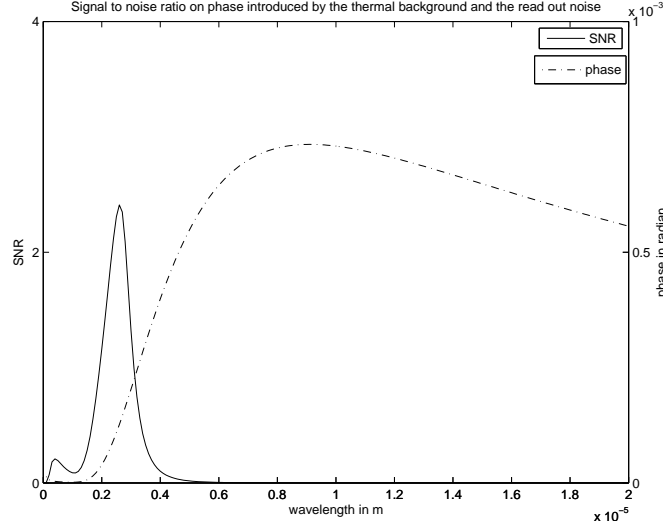
Figure 4. : Signal to noise ratio for an closure phase on HD108147 with an exposure of 600 hours.

Where $N(\lambda_i)$ is the total number of photon per channel λ_i, σ_{phot}^2 is the photon noise, σ_{read}^2 is the read out noise, and σ_{th}^2 is the variance of the thermal noise. M is the number of frames, np the number of pixel per spectral channel, C the contrast and n_{tel} the number of telescopes.

The signal to noise ratio defines that the best window for a three 40cm telescope interferometer is the K band. The simulated interferometer has a 200 m baseline, the exposure time is 10ms, and the $\delta\lambda$ of 0.1 μmeter. For comparison the integration time needed to reach a signal to noise ratio over 3 in the most favorable case: GJ86 is 10 h and for the farest: HD179949 is 200 h and for HD108147 is 600 h. The integration time needed to reach such signal to noise ratio with AMBER is for GJ86 1h, for HD179949 3h, and for HD108147 50h.

If just the thermal background gain is took into account, the signal to noise ratio of an interferometer composed by three 8 meter telescope at Paranal will be equivalent to one composed by three 5 meter telescopes at Dome C. As the seeing is better at Dome C, the adaptive optics of a telescope at Dome C should be better than the one at Paranal, and the total flux transmissions should be better. The transmission could be 3 times better for an interferometer at Dome C than the same at Paranal, the 8 m Paranal telescope are corresponding to a 3.5 m Dome C telescope in the case of differential color measurement.

The signal to noise ratio of the HD108147 is plotted on the figure 4.

As the Dome C atmosphere is stable enough to allow a 10h integration time observation of some hot Jupiter should be possible.

4. MYKÉRINOS AN INTERFEROMETER PROTOTYPE AT DOME C

Our laboratory propose to develope an optical interferometric array: KEOPS.(Vakili 2005 [3]) This interferometer will be composed by thirty six 1.5 meters telescopes deployed on 3 concentric rings with a maximal diameter of 1 km. Before building such complex interferometer the creation of a smaller interferometer would be carried out in order to validate the technical choices: Mykérinos. Mykérinos will be composed by three 40 cm telescopes with a 200 meters baseline. It will work in phase closure in order to remove instrumental and atmospheric phases (Segransan 1999 [10] Danshi, 2006 [11]). As shown on the last subsection this prototype is very promising for astrophysics. Such small interferometer can already study hot Jupiter, high contrasted binaries, and measure fundamental parameters like star diameters, or star masses.

4.1. Mykérinos Challenges

This interferometer will allow the confirmation of technical design for future Antarctica interferometer. Working in critical locations like Dome C, requires a high system automation for avoiding human interactions. The present logistics does not allow the presence of large team at Dome C and the temperature over winter do not allow instrumental adjustments. The system should be able to work at low temperature (190°K) with a low water concentration. An other critical technical point for this interferometer is to define the best way to get rid of the ground layer. Two solutions are actually considered : using ground layer adaptive optics or raising the telescopes on the top of 30 meter towers.

4.2. Mykérinos design and forthcoming step

Mykérinos will be composed by three 40 cm telescopes. The maximal base line is 200 meters. The flux from the telescopes are injected in fibers in order to be transported to the delay lines. The main problem is the chromatic dispersions which should be studied in order to find a compromise (Vergnole, 2005 [12]). According to the turbulence measured by Aristidi (Arisitidi, 2005 [4]) if the telescopes are over 30m towers, a tip tilt mirror should be enough to remove the effect of the atmosphere from visible to 2 μm. The beam combiner could be integrated optics techniques in order to have a high efficiency (Lebouquin, 2006 [13]).

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